PARADIGM: The Partnership for Advancing Interdisciplinary Global Modeling

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LONG-TERM GOALS

To develop an efficient, community-based coupled biogeochemical-physical modeling framework that will enable the addition of new oceanographic processes in a straightforward and transparent manner, allowing new model structures to be developed and explored as our understanding of ocean ecology and biogeochemistry improves.

To develop such a modeling framework within the context of our initial, specific overarching scientific focus: **an inter-comparison study between the subtropical-subpolar gyre systems of the North Pacific and North Atlantic basins, including an explicit coastal component, with particular emphasis on understanding:**

- new paradigms for physical and chemical control of plankton community structure and function,
- the consequences for biogeochemical cycling,
- the effects of sub-mesoscale and mesoscale forcing, and
- the dynamics of long-term, climate driven ecosystem regime shifts.

To meet the challenge of **merging observations and models** through

- advanced data assimilation techniques,
- development of interdisciplinary data products for incorporation into models, and
- application of new statistical and complex dynamical systems analysis techniques.

The merging of observations and models supports **a rigorous model validation program** that is central to PARADIGM**.**

OBJECTIVES

Our primary scientific objective is to improve our understanding of the mean state, seasonal cycle, and natural interannual to decadal variability of global and basin-scale biogeographical patterns. Why do different ecosystems reside where they do? What combination of forcing and biological responses

drives the observed long-term variability and apparent ecosystem regime shifts? The intrinsic scales of ocean ecology are set by the growth and removal of phytoplankton, with time-constants of one to a few days. Our project scope must, therefore, encompass the range of coupled dynamics of ocean ecology, biogeochemistry, and physics on scales from sub-diurnal to multi-decadal and submesoscale to global.

The project can be divided into four major scientific themes, with associated questions:

1) Biogeochemical cycles. *What factors govern phytoplankton biomass, productivity and export, the net remineralization of organic matter below the euphotic zone, and the spatial (e.g., biogeographical regimes) and temporal (e.g., climate regime shifts) variations in these global processes?* Field studies from the JGOFS era demonstrate quite clearly the critical roles for particular locations and times of multiple limiting nutrients (e.g., nitrogen, silicate, and iron), ratios of which strongly influence biogeochemical cycling. We know that physical variability and grazing modulate biological responses, and that changes in species composition and functional groups are involved. Descriptions of ecological, top-down controls and the interactions amongst these processes are not well constrained, however. Consequently, a second theme will focus squarely on ecosystem processes.

2) Community structure. *What processes govern plankton community structure and function and how do physical-chemical-biological interactions influence biogeochemical processes in the ocean system?* We begin with a widely accepted, but relatively poorly documented, two-state ocean model, with a near-uniform background state dominated by small-celled microbial plankton, and a highly episodic and variable component of larger cells (diatoms, mesozooplankton, gelatinous plankton), which contributes most of the export. The responses of key planktonic functional groups (nitrogen fixers, calcifiers, etc.) are also important because they influence differentially the cycling of nutrients and carbon. The two-state ocean model rests strongly on the hypothesis that physical perturbations drive the proliferation of larger cells and resultant enhanced export. Our third theme examines this forcing.

3) Scales of physical forcing. *How do mesoscale and sub-mesoscale physical variability impact ecosystem fluxes and community structure?* Mesoscale variability and disturbance are fundamental aspects of the marine system, not simply noise. The scientific details of how transient ecosystem response to perturbations rectify into large-scale or long-term variability in ecosystem structure and biogeochemical cycling are not well known, however. Present computational constraints prohibit full numerical resolution of all scales of interest, requiring technical advances in multi-scale grid-nesting, heterogeneous and adaptive grids, and subgridscale parameterizations. These and other constraints on interdisciplinary modeling provide the focus for our fourth theme.

4) Advanced interdisciplinary models. *How do we best merge observations and models?* Biogeochemical and ecosystem models are powerful tools to analyze the behavior and dynamics of complex marine ecosystems, but at their core are data driven. Unlike ocean physics, we do not have a Navier-Stokes law for biology. However we do have strong ‘first principles’ constraints, e.g., size vs. respiration, nutrient limitation vs. stoichiometry, etc., so it is possible to develop detailed models based on fairly general biological characteristics such as size and functional groups. The new models will predict much more than chlorophyll or nitrogen. Progress in merging observations with model predictions will require new statistical and complex dynamical systems analysis techniques, the development of new (e.g., bio-optical, multivariate) data products for incorporation into models, innovative data visualization, rigorous model-data evaluation, and greater reliance on data assimilation.

APPROACH

PARADIGM is a group of 16 scientists committed to building and deploying new, advanced models of ecology and biogeochemistry for understanding and predicting the future states of the ocean. The group combines expertise of observers and modelers, ecologists and physicists, biogeochemists and numerical specialists. Our overall scientific goal is a rigorous, model- and observation-based intercomparison of ecosystem/biogeochemical dynamics of the North Pacific and Atlantic subtropical - subpolar gyres. Our central objective is creation of new global ocean biogeochemistry community models, comprising complex ecosystem dynamics based on functional groups (e.g., *Archaea*, diatoms, copepods, gelatinous predators), individual keystone species (e.g., *Trichodesmium, Euphausia superba*) and multielement limitation and cycling (e.g., C, N, P, Si, Fe). The physical model platform is composed of a hierarchy of mature, general circulation models each the focus of extensive community model development programs. PARADIGM models will be capable of emergent behavior testing the hypothesis that fundamental regime shifts occur in response to climate change. Community models will be developed by interdisciplinary teams devoted to five program elements: (1) data fusion, synthesis and validation; (2) ecosystem model development; (3) high-resolution basin scale and regional process studies; (4) focus sites (i.e., regional test-beds) and (5) numerical method development (including data assimilation).

WORK COMPLETED

The program is just finishing its first 6 months of existence and hence has no significant work completed at this time.

RESULTS

Again, the program is just completing its first half year of a five year, renewable program and has no significant results to report at this time. This report does come just two weeks ahead of our first annual PI meeting, to be held at Woods Hole Oceanographic Institute 29-31 Oct, 2002.

IMPACT/APPLICATIONS

PARADIGM will develop **new community models of ocean biogeochemistry and ecology on global scales**, comprising complex ecosystem dynamics based on functional groups (e.g., *Archaea*, diatoms, copepods, gelatinous predators), individual keystone species (e.g., *Trichodesmium, Euphausia superba*) and multi-element limitation and cycling (e.g., C, N, P, Si, Fe). These models will include **new parameterizations of mesoscale and submesoscale processes** that are especially important in biological/physical coupling. **Data assimilation and data fusion** will be used to improve model formulation and to validate model performance. New approaches to **software development** will be used to simplify the addition of new ocean processes. The models will be capable of emergent behavior, testing the hypothesis that fundamental **domain shifts occur in response to climate change.**

PARADIGM will **improve linkages between modelers and field oceanographers** by creating an environment where model assumptions can be explored, model performance rigorously evaluated, and new ideas and hypotheses formulated and tested. Through regular interactions, data visualization, and focused workshops, PARADIGM will serve as an **intellectual hub for the study of ocean ecology and biogeochemistry** with numerical models as the tool. By making such models more transparent to

the non-modeler, we will enable the study of complex, global-scale processes in a rigorous open manner.

TRANSITIONS

To benefit from relationships outside our consortium, a fundamental objective will be *to make all of our research widely available to the scientific community*, both through traditional mechanisms (e.g., workshops) and innovative modes of communication (web-based interactive exchanges). This includes the distribution of forward model and data assimilation products, computational algorithms, etc. through workshops, summer schools, etc.